APPARATUS AND METHODS FOR ACCOMMODATING LOOPS OF OPTICAL FIBER

Field of the Invention

The present invention relates to optical fiber, and more particularly, to apparatus and methods for accommodating a length of optical fiber, such as, for example, a length having a plurality of loops of optical fiber.

Background

Optical fiber is highly desirable as a medium for transmitting, conditioning or even generating optical energy. Such optical energy can, but need not in all cases, carry information, such as voice or data signals. Optical fiber can, depending on its design, be suitable for use over long as well as short distances, provide low loss as well as a high bandwidth, and can be insensitive to electromagnetic interference. The bandwidth of a single optical fiber is enormous, and can be enlarged even further using optical multiplexing techniques.

In many applications the optical fiber being used is quite mechanically flexible, and must be used in longer lengths, such as when the fiber is used in, for example, amplifiers, lasers or delay lines. In such applications the fiber is typically wound about the outside of a support structure, such as a tube, such that the fiber can be more efficiently stored and take up less physical space, which can be at a premium. Such a technique for accommodating a longer length of fiber, though widespread, is not without certain disadvantages, and in certain instances improvements would be welcome.

Summary of the Invention

It is an object of the present invention to address one or more disadvantages or drawbacks of the prior art.

In one aspect of the invention, there is provided an apparatus for accommodating optical fiber, comprising a body having an inwardly facing surface for receiving a plurality of loops of a length of optical fiber, where the body includes at least a portion wherein the inwardly facing surface is continuous between two adjacent loops.

The surface can be adapted such that at least the majority of all of the loops to be received by the surface will be received so as to be substantially coaxial. The surface can comprise a helical groove for receiving the loops of optical fiber.

In another aspect, there is provided an optical apparatus, comprising a length of optical fiber comprising a rare earth, the length of optical fiber comprising a plurality of loops and a body comprising an inwardly facing surface receiving the plurality of loops of the length of optical fiber. One of more of the loops can be circular. One of more of the loops can be non-circular, such as by having, for example, an oval shape. Two or more of the loops can be coaxial. In one practice, all loops received by the inwardly facing surface are substantially coaxial. The inwardly facing surface can comprise a helical groove receiving the loops of optical fiber.

Responsive to receiving light of a first wavelength the rare earth can provide light of a second wavelength that is different than the first wavelength and the fiber can be normally multimode at the second wavelength. The loops can be shaped such that higher order modes are attenuated substantially more than a fundamental mode of the fiber.

The apparatus can comprise a light source optically coupled to the optical fiber for providing the light of the first wavelength. The apparatus can also comprise a second light source optically coupled to the optical fiber for providing light of the second wavelength. The apparatus can comprise at least one fiber grating, which can reflect light of a selected wavelength, such as, for example, light of the second wavelength.

In another aspect, apparatus according to the invention, such as the apparatus described elsewhere herein as having a body, can comprise a second body that can be mated with the body, where the second body has an outer surface that faces the inwardly facing surface of the body when the bodies are mated. In one practice, the second body can be removeably and replaceably mated with the body. For example, the second body can comprise a split ring that can be compressed for facilitating mating of the second body with the body.

In yet an additional aspect, the invention can provide an optical apparatus comprising first and second bodies adapted for being mated together to define a plurality of passages for housing a plurality of loops of a length of optical fiber. The plurality of loops can be coaxial, and alternatively or additionally, can have substantially the same radius of curvature. The plurality of passages can comprise a helical passage. Each of the plurality of passages can comprise a closed cross section.

The invention can also include methods. In one practice, the invention provides a method of accommodating a loop or loops of optical fiber, comprising the steps of providing a body; providing a length of optical fiber, the fiber comprising a rare earth; and receiving a plurality of loops of the fiber with a surface of the body, the plurality further being received such that the body can physically expand without subjecting the plurality of loops to a substantial increase in tension. The body can comprise an inwardly facing surface for receiving at least part of the outer face of each of the plurality of loops. The inwardly facing can comprise a helical groove for receiving the plurality of loops. All of the loops of the plurality can be coaxial. Alternatively or additionally, all of the loops can have substantially the same shape.

A body of an apparatus according to the invention can comprise at least one of aluminum and copper, and can generally comprise a ring shape. The apparatus can comprise means for increasing heat transfer to or from the body. The apparatus can comprise at least one passageway for a section of the length of fiber to pass from the plurality of loops. The passageway can be arranged such that the section of the length of fiber from the loop enters the passageway substantially along a tangent to one of the plurality of loops. The apparatus can comprise the length of optical fiber.

Further advantages, novel features, and objects of the invention will become apparent from the following detailed description of non-limiting embodiments of the invention when

considered in conjunction with the accompanying FIGURES, which are schematic and which are not necessarily drawn to scale. For purposes of clarity, not every component is labeled in every one of the following FIGURES, nor is every component of each embodiment of the invention shown where illustration is not considered necessary to allow those of ordinary skill in the art to understand the invention.

Brief Description of the Drawings

FIGURE 1 is a perspective view of one embodiment of an apparatus according to the invention;

FIGURE 2 is a cross section of the apparatus of FIGURE 1, taken along section line 2-2 shown in FIGURE 1;

FIGURE 3 is a view of the body of FIGURE 1 taken along section 3-3 of FIGURE 1;

FIGURES 4A-4B illustrate alternative manners in which an inwardly facing surface of a body according to the invention can be adapted to receive optical fiber;

FIGURE 5 is a perspective view of another embodiment of a body according to the invention;

FIGURE 6 is a perspective view of a body that can be mated with the body shown in FIGURE 5;

FIGURE 7 is a perspective view showing the body of FIGURE mated with the body of FIGURE 5;

FIGURE 8 is a cross section of FIGURE 7 taken along section line 8-8 of FIGURE 7;

FIGURE 9 illustrates an additional embodiment according to the invention;

FIGURE 10 is a perspective view of one embodiment of an apparatus for disposing an optical fiber with an optical apparatus intended to accommodate the optical fiber;

FIGURE 11 is a plan view of the apparatus of FIGURE 10;

FIGURE 12 illustrates a perspective view of another embodiment of an apparatus for disposing an optical fiber with an optical apparatus intended to accommodate the optical fiber;

FIGURE 13 is a plan view of the apparatus of FIGURE 12.

Detailed Description

FIGURE 1 is a perspective view of one embodiment of an optical apparatus **10** according to invention. The optical apparatus **10** can include a body **12** comprising a top surface **13**, an outer surface **14** and an inwardly facing surface **16**. The inwardly facing surface **16** can receive a plurality of loops of a length of optical fiber, and can include a plurality of grooves or slots, as indicated generally by reference numeral **18**. Typically the plurality of loops of optical fiber, which are not shown in FIGURE 1, as well as the plurality of grooves or slots, are coaxial about the common axis **20**. Furthermore, each of the plurality of loops of optical fiber, when received by the inwardly facing surface **16** of the body **12**, is typically circular. The plurality of loops can have substantially the same radius of curvature, which radius is indicated by the designation "R" in FIGURE 1. The body **12** is shown in FIGURE 1 as having a general ring shape, though other shapes are possible and within the scope of the invention. An inwardly facing surface is one wherein a normal vector to the surface has a component that is perpendicular to the axis **20**, and this perpendicular component points inwardly toward the axis **20**. In other words, comparing the region bounded by a loop of fiber to the region outside the loop of fiber, the normal to the surface would be said to point more toward the region bounded by a loop of the fiber rather than toward the region outside of the loop of fiber. R can be less than about 10 mm, less than about 9 mm, less than about 8 mm, less than about 7 mm, less than about 6 mm, or less than about 5 mm.

Typically the plurality of grooves **18** shown in FIGURE 1 are formed from a single groove that is helical, meaning that it advances along the axial direction **20**, such as, for example, screw threads are known to advance. Typically the pitch (spacing of the centers of the grooves) of the grooves **18** is on the order of the diameter of the fiber to be received by the inwardly facing surface **16**, such as, for example, by being from about 1 to about 5 diameters of the fiber to be received, or, as another example, by being approximately 1.5, 2.5, 3.5, 4.5 or 5.5 diameters of the fiber to be received.

The body **12** can comprise one or more of a variety of materials, such as, for example, a metal, a ceramic or glass. The body **12** can be unitary. Typically the body **12** is unitary, and, for example, is formed by machining an appropriate piece of material, such as a metal or alloy of various metals. Copper and aluminum are both good choices because they readily conduct and/or absorb heat generated by the optical fiber loops received by the inwardly facing surface **16** away from the optical fiber loops. Alternatively the body **12** can be integral, that is, the body **12** can be formed by assembling different parts together, such as by first forming different parts to be assembled in separate steps, or can have discrete portions that are formed of different materials. For example, an alternative technique for forming the plurality of grooves is to coat a first portion of the body **12** with a deformable material and press, such as by, for example, expanding, a form (or even the loops of fiber) into the material to create grooves. The apparatus **10** thus comprises the deformable material as well as the first portion of the body.

FIGURE 2 is a cross section of the apparatus of FIGURE 1, taken along section line 2-2 shown in FIGURE 1. Illustrated in cross section are the inwardly facing surface **16**, the grooves **18**, loops **40** of optical fiber, and the outer face **42** of one of the loops **40**.

The outer diameter of an optical fiber can depend on the application for which the fiber is intended. In many applications, optical fiber having an outer diameter of 125 microns is standard. In other applications, an optical fiber of the present invention can have an outer diameter of several hundred microns or even larger. In the embodiment shown in FIGURES 1 and 2, the dimensions of the grooves **18** can be selected for proper reception of the loops by the inwardly facing surface **16**. Typically the inwardly facing surface **16** is spaced in the radial direction no more than one or two fiber diameters from the outer face **42** of the loop of optical fiber when the loops are received by the inwardly facing surface **16**. The loops of the optical fiber preferably contact the inwardly facing surface **16** at many locations when the loops are received by the inwardly facing surface **16**.

The depth d_1 of the grooves **18** preferably exceeds the outer diameter d_2 of the optical fiber of the loop **40**, such that the loops of optical fiber can be inside the grooves, as shown in FIGURE 2.

The inwardly facing surface **16**, and in particular the plurality of grooves **18**, should be substantially free of burrs so as to avoid damaging the loops of optical fiber. The inwardly facing surface **16** and the grooves can be shot peened as part of the process of fabricating the body **12**.

The inwardly facing surface **16** need not receive the entire length of a loop of optical fiber, typically approximately equal to $2\pi R$, where R is the radius of curvature of the loop and the diameter of the fiber is neglected. For instance, part of the body **12** could be cut away, such that the body comprises a split ring. However, it is preferable that the surface receive at least the majority of the length of each of the loops.

Returning to a consideration of FIGURE 1, the body **12** can include at least one passageway **28** (four passageways are shown in FIGURE 1) for a section of the length of optical fiber to pass from the plurality of loops. Such a section can be a pigtail for allowing optical communication with the loops of fiber. First and second sections of the length of optical fiber are indicated by reference numerals **30** and **32**, respectively, and are shown as dotted lines, as the length of optical fiber is not otherwise shown in FIGURE 1. Preferably, the passageway **28** is arranged such that the section of the fiber from the loop enters the passageway substantially along a tangent to the loop. Brief reference is made to FIGURE 3, which is view taken along the section line 3-3 of the body **12** of FIGURE 1, and which shows an individual loop **70**, a tangent line **72** to the loop, as well as a passage **28** and the section of fiber **30**. The apparatus **10** can accommodate two or more separate coils, where each coil includes one or more loops, and can include an appropriate number of passageways such that the lengths of fiber can pass to or from the coils.

The body **12** preferably includes a portion **75** wherein for at least a plurality of loops the inwardly facing surface is continuous between adjacent loops, as indicated by reference numeral **79** in FIGURE 2.

Note that the length of optical fiber can include splices, and different types of fiber can be spliced together to form the length of optical fiber. For example, in one practice the at least one of the loops of a fiber received by the inwardly facing surface **16** in FIGURE 1 comprise a rare earth, and the sections **30** and **32** do not comprise a rare earth, and the sections and the at least one loop can be spliced together.

In many examples of prior art practice, loops of fiber are superposed over other loops of optical fiber, such as by winding several layers of loops over a tube or rod. In one practice of the invention, the apparatus **10** does not accommodate any loops that are superposed over other loops of optical fiber. In other practices of the invention, loops are superposed over one another.

In one embodiment of the invention, the inwardly facing surface can comprise grooves, as described above. In other embodiments, an optical apparatus comprises a body having an inwardly facing surface receiving a plurality of loops of optical fiber, wherein the inwardly facing surface can be a simple flat surface.

FIGURES 4A and 4B illustrate additional and/or alternative approaches for adapting a surface to receive the outer perimeter of a loop of optical fiber. FIGURE 4A illustrates a surface **16** that includes surface portions **78** formed by shoulders **80**. FIGURE 4B shows material **84**, which can be, for example, a gel, viscous substance or adhesive material.

The optical fiber can comprise a rare earth. The rare earths include elements 57-71 of the periodic table (e.g., lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium). Responsive to receiving energy of one wavelength, known in the art as the "pump" wavelength, certain rare earths can provide optical energy of a different wavelength. Fibers doped with a rare earth can thus be used as light sources, such as for example, super luminescent light sources and lasers that provide light at the second wavelength. Often the light at the second wavelength is of higher quality in terms of divergence, spatial and temporal coherence and the like. In many applications a fiber comprising a rare earth thus acts as a brightness converter that receives low quality pump and converts that light to higher quality light at a more desirable wavelength. Fibers doped with rare earths can also be used as amplifiers that amplify a signal of the other wavelength propagated by the fiber.

The process of converting pump energy to optical energy of a different wavelength is not always 100% efficient, and some energy is dissipated as heat in the optical fiber, which heat energy should be extracted from the optical fiber to avoid overheating of the fiber. Coiling the fiber on the inside of the body **12** can allow the natural spring tension of the loop, which tends to cause the loop(s) of optical fiber to expand, to promote reception of the outer faces of the loops

by the inwardly facing surface **16**, which can in turn promote heat transfer between the loops of the optical fiber and the body **12**.

Of course the apparatus **10**, such as the body **12**, in some instances, may heat up sufficiently, responsive to receiving heat energy from the loops of optical fiber, such that heat should be removed from the apparatus **10**. Whether the body **12** heats up appreciably depends on the rate of transfer of heat away from the body **12** in relation to the rate of transfer of heat from the loops of optical fiber to the body **12**, as well as the heat capacity of the body **12**.

The apparatus **10** can include various means for promoting heat transfer to and/or from the apparatus **10**. For example, the body **12** of the apparatus **10** can include fins, grooves, holes, or other well known expedients that increase the surface area of the apparatus for increasing heat transfer to or from the apparatus. Heat can be transferred in a variety of manners, including convection, conduction and radiation, as is known in the art, and any one of these mechanisms, alone or in combination, can be exploited to provide means for transferring heat to or from the apparatus **10**.

The pitch of the optical fiber can be determined, at least in part, by considerations related to heat transfer. For example, if the pitch is too low, the portion of the body **12** interposed between adjacent loops of fiber (see reference numerals **90** and **92** in FIGURE 2, where reference numeral **90** indicates generally adjacent loops and reference numeral **92** indicates the portion interposed between adjacent loops) may become a "hot spot" that is elevated to too high a temperature. Such hot spots are preferably avoided. Judicious consideration of factors such as the pitch of the loops, the heat load from the loops of optical fiber, the nature of the heat transfer from the loops to the body **12**, the heat capacity of the body **12**, and the provision for transferring heat from the body **12**, as well as other like factors, can be taken into account to ensure that hot spots are less likely to occur.

FIGURE 5 illustrates another embodiment of an apparatus **110** according to the invention. The body **112** comprises a top surface **113**, an outer surface **114**, an inwardly facing surface **116**, a plurality of grooves **118** and the passageways **128A**. As with FIGURE 1, a length of optical fiber comprising a plurality of loops is not shown, though one of ordinary skill in the art, in light of the disclosure herein, can readily appreciate that the loops of optical fiber are received by the inwardly facing surface **116**. Note that the body **112** can include the passageway

128B that is generally opposed to passageway **128A**. The apparatus **110** can include planar surfaces **130A** and **130B** that intersect the passages **128A** and **128B** respectively. The planar surfaces **130A** and **130B** can be flat and are oriented at the angle α shown in FIGURE 5. The angle α is approximately 160° in FIGURE 5, and the angle α can more generally range from 0° to 360°. In one embodiment of the invention, the angle α can be from about 25° to about 180°. The apparatus **110** can also include provision for increasing heat transfer to or from the body **112**, as indicated by reference numeral **140**. The body **112** includes a plurality of protuberances **144**, axial grooves **150** and azimuthal grooves **154**.

In certain practices a material, such as a grease, gel or the like, can be used with the loops of the optical fiber, such as by interposing the material between or near the inwardly facing surfaces **16, 116** and the loops of optical fiber. The material can promote heat transfer between the loops and the body **12, 112** and can be applied to the fiber prior to reception of the loops by the inwardly facing surface, or applied after reception, or both. The material can comprise, for example, a gel, liquid or gas.

Note that if the body does heat appreciably, in one practice of the invention, the body **12, 112** will typically expand outwardly. It is well known in the prior art to wind an optical fiber around a tube or rod, such that the tube or rod receives the at least part of inner faces of the coils of optical fiber. In this prior art technique, any outward expansion of the tube or rod, such as due to heating, can be disadvantageous in that it increases the tension in the optical fiber, which can lead to a change in the optical properties of the fiber or promote earlier failure of the fiber. It may also be necessary to wind the fiber about the rod with a certain amount of tension so as to promote reception of the coil by the tube or rod, as the natural tendency of a coil of fiber to spring apart does not tend to promote reception of the fiber by the prior art rod or tube, as it can with embodiments of the present invention. Practice of the present invention, in certain embodiments, can allow substantially tension-free accommodation of a loop or plurality of loops of optical fiber.

With reference to FIGURES 6 and 7, an apparatus according to the invention can comprise a second body **170** that can be mated with the body **112**. FIGURE 6 illustrates the body **170** alone and FIGURE 7 illustrates the body **170** mated with the body **112**. With reference to FIGURE 6, the body **170** can comprise an outwardly facing surface **174**, a top

surface **176** and an inwardly facing surface **178**. The body **170** can comprise provision for promoting heat transfer to or from the body **170**, as indicted by reference numeral **190**.

Preferably the second body **170** can be removeably and replaceably mated with the body **112** for ease of removal of one body from the other. For example, as shown in FIGURE 6, the second body can comprise a gap **194** such that the body can be compressed and can expand to be mated with the body **112**. The body **170** can thus comprise a split ring that can be compressed for facilitating reception of the second body **170** within the body **112**. FIGURE 8 is a cross section of FIGURE 7 taken along section line 8-8. The surface **174** of the second body **170** can face the inwardly facing surface **116** of the body **112**. The surface **174** can be spaced, along the radial direction, from the surface **116**, as indicated by reference numeral **180**. The spacing **180** is typically on the order of a one to a few outer diameters of the optical fiber, such as for example, 1-10 diameters, or, more preferably, 1-5 diameters. As indicated in FIGURE 8, the spacing need not be the same everywhere, and in various embodiments of the invention the foregoing recitation of spacing dimensions can represent the average spacing, or alternatively, the closest spacing, as indicated by reference numeral **180**, or, as another example, the maximum spacing.

The outwardly facing surface **174** need not be flat, but optionally can comprise a plurality of grooves **200**. The grooves **200** can oppose and can be in register with the plurality of grooves **118** comprised by the inwardly facing surface **116**, as shown in FIGURE 8. The outwardly facing surface **174** can also optionally comprise one more of the protuberances, one of which is indicated by reference numeral **202**. The protuberances can oppose the grooves, and can be designed to penetrate the grooves.

The body **170**, when mated with the body **112**, defines a plurality of passages **208** for housing a plurality of loops of a length of optical fiber. The passages **208** are shown in cross section in FIGURE 8, and when viewed in cross section can be generally closed. The spacing **180** does represent an opening between adjacent passages. In one embodiment of the invention, any gaps or spacing in the perimeter of the passages are less than the diameter of the optical fiber. For example, the spacing **180** can be less than the outer diameter of the fiber of the loop **140**. In one embodiment of the invention, the majority of length of the perimeter of each of a plurality of the passages, when viewed in cross section, is closed. The outwardly facing surface

174 can contact the inwardly facing surface such that each of a plurality of passages is completely closed when viewed in cross section.

Preferably the surface **174** does not contact the opposing fiber loop **140** received by the inwardly facing surface **116**. One of the bodies can include a recess that is received by a shoulder of the other of the bodies. For example, as shown in FIGURE 8, the second body **170** can include a recess **195** that receives a shoulder **198** of the body **112**. Thus in one practice of the invention the body **170** contacts the body **112** but is appropriately spaced from the fiber loop **140** when the body **170** is received by the body **112**. In another practice of the invention, the body **170** can contact the fiber loops. Preferably the second body **170**, when received by the body **112**, does not substantially compress the loops received by the inwardly facing surface **116**, and hence does not affect the optical properties of the loop **140** to detrimentally affect the desired optical performance of the loop **140**.

Certain features of the invention are shown in the FIGURES herein, such as in FIGURES 1, 5 and 6. A patent disclosure is not intended to be an encyclopedic recitation of combinations of features that are deemed to be within the scope of the invention. For example, one or more of the features shown in FIGURE 5 can be included with one or more features shown in FIGURE 1, as is readily appreciated by one of ordinary skill in the art in light of the disclosure herein. For example, in one practice the invention, the embodiment shown in FIGURE 1 can include opposed passages, but need not include the provisions shown in FIGURE 5 for promoting heat transfer, or the flats shown in FIGURE 5. The foregoing comments apply to the FIGURES discussed below.

In certain applications multimode fibers and/or fibers having rather low numerical apertures and larger core diameters can have advantages. For example, it is desirable to increase the power handling capability of optical fibers, and in particular to increase the power handling capability of fibers that are used in fiber lasers and fiber amplifiers. Unfortunately, nonlinear processes, such as stimulated Brillouin scattering (SBS) and stimulated Raman scattering (SRS) are responsible, in large part, for limiting the power handling capability of fibers and hence the power output of fiber lasers and amplifiers. Though these processes are complex, each can be reduced by limiting the power density in the core of the fiber. This can be accomplished by using a larger core fiber that in addition has a lower numerical aperture, such that the fiber has a larger mode field diameter. Essentially, the power of the light propagating along fiber is more

spread out, such that the power density in any given area of the fiber is reduced. Fibers having large core diameters support multiple spatial modes. The presence of such modes tends to degrade the quality of the light provided by the fiber.

One useful technique described in U.S. Patent No. 6,496,301, issued on December 17, 2002 to Koplow, Kliner and Goldberg, involves coiling a normally multimode fiber to filter out, via bend loss, selected higher order modes. The selected higher order modes experience substantially higher bend loss than the non-selected (lower order) modes. All of the higher order modes can be caused to experience substantially higher attenuation such that the fiber operates in a single mode. Such a technique allows higher power operation of the fiber while maintaining the quality of the light provided by the fiber. Typically the fiber has a rather low numerical aperture, such as, for example, a numerical aperture no greater than 0.12, no greater than 0.09, or even no greater than 0.06. A numerical aperture of about 0.05 to about 0.06 can be useful. An optical fiber can have a core diameter of greater than 10 microns. The core diameter can be at least 20 microns. In certain practices of the invention, the core diameter can be no less than 30 microns, no less than 50 microns, or even no less than 100 microns. It can be important in certain applications that light have a particular polarization. Optical fiber can be coiled to provide certain properties relating the polarization of light propagated by a fiber. For example, birefringent fiber, such as polarization maintaining fiber, can be coiled so as to become a polarizing fiber, wherein one of the polarizations of a mode, such as the fundamental mode, is attenuated substantially more than the other polarization of that mode. See, for example, published U.S. Patent Application U.S. 2003/0086668, in the name of inventors Kliner and Koplow (published May 8, 2003), and published U.S. Patent Application U.S. 2002 /0159139, in the names of inventors Koplow, Kliner and Goldberg, published October 31, 2002. The foregoing U.S. Patents and applications are herein incorporated by reference to the extent necessary to understand the present invention.

As noted above, the optical fiber can comprise a rare earth. Additionally or alternatively, the optical fiber can be a double clad fiber. For example, the fiber can comprise a core comprising an index of refraction, a first cladding disposed about the core, and a second cladding disposed about the first cladding, where the first cladding comprises a first index of refraction and the second cladding comprises a second index of refraction that is less than the first index of refraction. Double-clad fibers are useful because they allow pump light to be more easily introduced to the core, as compared to single-clad fibers, and hence absorbed by the rare

earth. The pump light can be introduced to the large (compared to the core) inner cladding and will intersect the core as it propagates down the inner cladding and reflects, due to the difference in the indices of refraction of the inner and outer claddings, from the boundary between the inner and outer claddings. The absorption of the pump light by the fiber, typically measured in per unit length of the fiber, such as in dB/meter, is a useful figure of merit for a double-clad fiber. A high absorption per unit length of the fiber is desirable, and, for a given concentration of the rare earth, indicates more interaction between the rare earth and the pump light.

Double-clad fibers are known at least from the following U.S. Patents: U.S. Patent No. 3,808,549 issued to Maurer; U.S. Patent No. 4,815,079 issued to Snitzer et al.; U.S. Patent No. 5,533,163 issued to Muendel; U.S. Patent No. 5,864,645 issued to Zellmer et al.; U.S. Patent No. 6,157,763 issued to Grubb et al.; U.S. Patent No. 5,949,941 issued to DiGiovanni; and U.S. Patent No. 6,477,307 issued to Tankala et al. See also U.S. Patent No. 6,483,973 to Mazzarese et al.

With reference to the schematic illustration in FIGURE 9, an optical apparatus **300** according to the invention can also comprise a length of optical fiber **302**, where the length includes loops that include a rare earth, a body **310** comprising an inwardly facing surface receiving the loops of the optical fiber, a light source **380** optically coupled to the optical fiber **302** for providing the light of the first wavelength, as well as a second light source **385** optically coupled to the optical fiber **302** for providing light of the second wavelength. Techniques for optically coupling the light sources **380** and **385** to the optical fiber are well known in the art and need not be elaborated upon here. Such techniques include splicing, the use of an optical coupler, such as a tapered fiber coupler, side pumping of the fiber, such as the use of v-grooves and embedded mirrors and the like, as well as imaging optics, such as a pair of lenses. The optical apparatus **300** can comprise at least one reflector **392A**, such as a fiber grating, for reflecting light of the second wavelength. A second reflector, **392B**, which can also be a fiber grating, can be used to provide a laser cavity between the reflectors.

Optical sources are well known to those of ordinary skill in the art and can include, by way of example and not of limitation, lasers, optical amplifiers, semiconductors, such as light emitting diodes (LEDs) and diode lasers, and flash lamps.

FIGURE 10 is a perspective view of one embodiment of a first apparatus **422** for disposing an optical fiber **402** with an optical apparatus **410** intended to accommodate the optical fiber **402**. With reference to FIGURE 10, as well as FIGURE 11, which is a top view of FIGURE 10, the optical apparatus **410** can include at least one body. More typically, the optical apparatus **410** includes a first body **412** mated with a second body **470**, where the length of fiber **402**, when accommodated by the optical apparatus **410**, can be located between the first and second bodies, **412** and **470**, respectively. Preferably the first and second bodies can move relative to one another when mated for facilitating including a length of optical fiber **402** with the apparatus **410**, as will be apparent from the discussion below.

The apparatus **422** can include a clamp or chuck **441**, such as the triple jaw chuck shown in FIGURE 10, for engaging one of the bodies, such as, for example, the first body **412**. A rotational drive element **461**, such as, for example, a motor, is operatively coupled to the shaft **426** for rotation thereof, as indicated by reference numeral **463A**. The arm **458**, operatively coupled to the shaft **426**, engages the second body **470** for moving the second body **470**, as indicated by arrow **463B**. The arm **458** can include a spring loaded retractable pin **459**, and the second body **470** can include a recess or slot (not shown) for receiving the pin **459**. The pin **459** is normally urged outward and can be retracted by moving the tab **460** toward the shaft **426**. Second and third arms, **434** and **446**, respectively, are also operatively coupled to the shaft **426** for rotation therewith. The second arm **434** carries a spool of fiber **436** and the third arm **446** carries fiber drive element **452**, which can include the tractor **448** shown in FIGURE 10, that pulls fiber from the spool **436** and drives the fiber such that it is disposed with the optical apparatus **410**. The spindle **438**, which is coupled to the arm **434**, can rotationally mount the spool **436**. The optical apparatus **410** can comprise a passage into which the fiber is fed. Typically, the optical apparatus includes first and second bodies that define at least one passage therebetween. See for, example, the plurality of grooves **455**, which are bounded in part by an outwardly facing wall (which faces the inwardly facing wall **416** of the first body **410**) of the second body **470**. The tractor **448** can feed the fiber such that it is located between the first and second bodies **412** and **470**.

The tractor **448** can include wheels **449** for engaging and pulling the fiber, and a drive element (not shown), such as a motor, for driving the wheels **449**. The funnel **457** can guide the fiber to the tractor wheels **449**, and the guide tube, which can include a first part **456A**, spaced from a second part **456B**, so as to allow the drive wheels **449** to engage the fiber **402**.

Typically, the chuck **441** holds the first body **412** stationary and the second body **470**, which is the inner body as depicted in FIGURE 10, is operatively coupled to the shaft **426** and accordingly rotates. However, as appreciated by one of ordinary skill in the art, it is the movement of the first body **412** relative to the second body **470** that facilitates including the length of optical fiber with the optical apparatus **410**, and neither of the bodies need be stationary.

Note one or more of the arms **446**, **434** and **458**, the fiber drive element **452**, funnel **457**, feeder tube **456** and the spool of fiber **436** are operatively coupled to the shaft **426** for rotation therewith, as is the second body **470** via engagement with the pin **459**. With reference to FIGURE 11 (and also FIGURES 12 and 13, discussed below), the fiber is disposed with the optical apparatus **410** by passing through an inner outside region **417** meaning as used herein a region that is "inner" in that it is surrounded at least in part by the optical apparatus **410** but that is "outer" in that it is not part of the optical apparatus. For example, the region **417** is surrounded, and is also bounded, in both instances at least in part, by the inwardly facing surface **419** of the second body **470** and is clearly not part of the optical apparatus. (With regard to FIGURES 12 and 13, see reference numerals **617** and **619**.) The length of fiber can pass through the gap or aperture **494**, which also moves, responsive to rotation of the shaft **426**, as the fiber is disposed with the optical apparatus **410**. The length of fiber can be received by the inwardly facing surface **416** of the first body **412**. The inwardly facing surface **416** can include a plurality of grooves **455**, as previously discussed. Preferably any corners or edges formed by the gap or aperture have rounded edges to avoid damaging the optical fiber.

As appreciated by one of ordinary skill in the art appraised of the disclosure herein, the controller **464** can control the fiber drive element **452** and the rotational drive element **461** in a coordinated manner so as to properly dispose the fiber with the optical apparatus **410** so as to reduce the likelihood of adversely compressing or tensioning the fiber **402**.

Note that the optical apparatus **410** need not, in all cases, include the second body **470**. In this case, the retractable pin **459** may not be needed. The fiber **402** can simply be disposed with the inwardly facing surface **416** of the body **412**.

Reference is now made to FIGURE 12, showing another embodiment of the invention, and to FIGURE 13, which is a top view of the apparatus of FIGURE 12. FIGURE 12 illustrates a perspective view of a second apparatus **622** for disposing an optical fiber **602** with an optical apparatus **610** intended to accommodate the optical fiber **602**. The optical apparatus **610** can include at least one body, and more typically includes a first body **612** mated with a second body **670** such that one of the bodies can move (e.g., rotate) relative to the other of the bodies.

A rotational drive element **661** can be operatively coupled, via, for example, a friction drive wheel **627**, to the first body **612** so as to rotate the first body **612**, as indicated by reference numeral **663**. A base **633**, which can be secured in a vise, for example, can mount an assembly **635** that include the retractable pin **659**. The retractable pin **659** can engage the second body **670** so as to allow a difference in rotation speeds between the first body **612** and the second body **670**. Preferably, the second body **670** is held stationary. The fiber **602** can be provided from a spool (not shown).

The second base **639** can mount fiber drive element **652** and the first and second guide tube parts, **656A** and **656B**, respectively. The pin **631** can allow rotation of the fiber drive element **652** and first and second guide tube parts **656A** and **656B**, as indicated by reference numeral **666**. The spring **637** can urge the second guide tube part **656B** to approach and/or engage the inwardly facing surface **616**. The guide tube **656B** can include a tip **669** that can engage grooves (not shown in FIGURE 13) for disposing the fiber in the grooves. With reference to FIGURE 13, the guide tube **656** (the reference numeral **656** is used to refer to both guide tube parts **656A** and **656B**) and fiber drive element **652** can be pivotally mounted to the second base **639** such that the feed tube **656** and fiber drive element can pivot out of and into the page of FIGURE 13 (much like a turntable stylus arm). The second base **639** can include a yoke (not shown) that pivots relative to the second base **639** and that engages an outer surface of the first guide tube part **656A** for allowing the aforementioned pivoting. This pivoting action, indicated by reference numeral **665** of FIGURE 12, can facilitate reception of the fiber by the grooves **655** of the inwardly facing surface **616**, especially when the grooves **655** form a continuous helical groove. The guide tube can more readily follow the helical groove.

The second apparatus **622** of FIGURE 12, as is readily appreciated by one of ordinary skill in the art, can have several features in common with the apparatus **422** of FIGURE 10. For example, a controller **664** can coordinate operation of the fiber drive element **652** and rotational

drive element **627**, as discussed in conjunction with FIGURES 10 and 11. Reference is made to the discussion of FIGURES 10 and 11 for details of other features.

With reference to FIGURE 13, one part **656A** of the guide tube is spaced from the second part **656B** of the guide tube to facilitate driving the fiber **602**. It is considered beneficial that the spacing be kept as small as possible to minimize buckling or kinking of the fiber **602**. Ends of the guide tube nearer the tractor wheels can be shaped to match the contours of the tractor wheels. The end of the guide tube **669** can be positioned to allow the fiber to exit the tube as near the inwardly facing surface **616** as is practicable. Note that the guide tube parts **456A** and **456B** in FIGURES 10 and 11 are similarly spaced.

Several embodiments of the invention have been described and illustrated herein. Those of ordinary skill in the art will readily envision a variety of other means and structures for performing the functions and/or obtain the results or advantages described herein and each of such variations or modifications is deemed to be within the scope of the present invention. More generally, those skilled in the art would readily appreciate that all parameters, dimensions, materials and configurations described herein are meant to be exemplary and that actual parameters, dimensions, materials and configurations will depend on specific applications for which the teaching of the present invention are used.

Those skilled in the art will recognize or be able to ascertain using no more than routine experimentation many equivalents to the specific embodiments of the invention described herein. It is therefore to be understood that the foregoing embodiments are presented by way of example only and that within the scope of the appended claims and equivalents thereto, the invention may be practiced otherwise than as specifically described. The present invention is directed to each individual feature, system, material and/or method described herein. In addition, any combination of two or more such features, systems, materials and/or methods, if such features, systems, materials and/or methods are not mutually inconsistent, is included within scope of the present invention.

In the claims as well as in the specification above all transitional phrases such as "comprising", "including", "carrying", "having", "containing", "involving" and the like are understood to be open-ended. Only the transitional phrases "consisting of" and "consisting essentially of" shall be closed or semi-closed transitional phrases, respectively, as set forth in the

U.S. Patent Office Manual of Patent Examining Procedure §2111.03, 7th Edition, Revision 1. The phrase "one or more", "at least one" or the like is used at times to provide clarity; however, the absence of the employment of such a phrase is not to be taken to mean that a plurality is excluded. Absent some special definition to the contrary, the use of the term "a" or "one" carries the normal meaning in patent documents of "one or more" or 'at least one".